CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-217 SURPRISE VALLEY AND RELATED FAULTS, LASSEN AND MODOC COUNTIES, CALIFORNIA

by

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August 17, 1990

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INTRODUCTION

Potentially active faults in the Surprise Valley study area of southeastern Modoc County and northeastern Lassen County that are evaluated in this Fault Evaluation Report (FER) include faults that comprise the Surprise Valley fault, the Lake City fault, and numerous unnamed faults located east of the principal active trace of the Surprise Valley fault (Figure 1). The Surprise Valley study area is located in parts of the Cedarville and Fort Bidwell 15-minute quadrangles and the Eagle Peak, Eagleville, Hansen Island, Snake Lake, and Warren Peak 7.5-minute quadrangles (Figure 1).

Faults in the Surprise Valley study area are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active (Holocene) and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1988).

SUMMARY OF AVAILABLE DATA

The Surprise Valley study area is located in Surprise Valley, a north-trending structural basin (graben) bordered on the west and north by the Warner Mountains and on the east by the Hays Canyon Range (Nevada) (Figure 1). The Surprise Valley fault can be considered to be the boundary between the Modoc Plateau geomorphic province to the west and the Basin and Range province to the east. The study area is characterized by oblique Basin and Range extensional tectonics, which results in predominately normal faulting along north-trending faults and right-lateral strike-slip faulting along northwest-trending faults.

Topography in the study area ranges from the flat playa surfaces in Surprise Valley to the abrupt, rugged eastern escarpment of the Warner Mountains on the west side of Surprise Valley. Elevations in the study area range from approximately 1360 meters at Upper Lake playa to over 2740 meters in the Warner Mountains. Development in the study area is moderate to low. The small towns of Cedarville, Lake City, Ft. Bidwell, and Eagleville are located along the west side of Surprise Valley. Agriculture (farming and cattle) is the principal activity in the study area.

Rock types in the study area include Tertiary volcanic rocks exposed in the Warner Mountains that range in age from late Eocene through Miocene (Gay and Aune, 1958; CDWR, 1963; Hulbe and Emerson, 1969; Martz, 1970; Duffield and Weldin, 1976). Pliocene and Pleistocene basalt flows were mapped by Gay and Aune (1958) in the southern part of the study area. Quaternary deposits include late Pleistocene and Holocene alluvial and lacustrine deposits in Surprise Valley. High-stand shorelines of Lake Surprise, which occur at the 1,457-meter elevation (5,050-foot), are correlated with Lake Lahontan Pleistocene high stands. Hedel (1980) reported that Surprise Valley is filled with at least 2130 meters of Quaternary lacustrine and fluvial deposits, based on geothermal exploration data.

Mapping by Hedel (1980, 1984) will be evaluated in this FER. Previous mapping of the Surprise Valley and related faults by I.C. Russell (1884, 1885), R.J. Russell (1928), Gay and Aune (1958), and CDWR (1963) will not be evaluated in detail due to the relatively small scale and/or poor quality base maps.

Aerial photographic interpretation by this writer of faults in the Surprise Valley study area was accomplished using aerial photographs from the U.S. Department of Agriculture (BUW, 1955). In addition, U.S. Forest Service photos (MO 01, 1974) were inspected at the U.S. Forest Service office in Alturas in September 1989. The main emphasis of this FER is to photo-check the mapping of Hedel (1980, 1984) rather than complete an independent photo interpretation. To test the accuracy of Hedel's mapping, faults locally were plotted directly on aerial photographs and then transferred to base maps using a Bausch and Lomb Zoom Transfer Scope.

Four and one-half days were spent in the field in late September 1989. Selected fault traces were verified and subtle features not observable on the aerial photographs were mapped in the field. Soil pits were excavated to provide preliminary descriptions of soil development on selected geomorphic surfaces. Results of aerial photographic interpretation and field observations by this writer are summarized on Figures 2a and 2b.

SURPRISE VALLEY FAULT

Literature Review

The Surprise Valley fault is a 84 km-long, north-trending normal fault located along the east side of the Warner Mountains (Figures 1, 2a, and 2b). Hedel (1980) estimated that cumulative down to the east vertical displacement along the Surprise Valley fault is about 3800 meters. This estimate is based on the summation of the height of the southern crest of the Warner Mountains above the surface of Surprise Valley (1670 meters) and the estimated depth of alluvial fill in Surprise Valley (~2130 meters).

The Surprise Valley fault was first mapped by I.C. Russell (1884, 1885). Russell recognized that the Warner Mountains is a west-tilted fault block bounded on the east by the Surprise Valley fault (Photo 1). Russell noted that the Surprise Valley fault displaced

Quaternary lacustrine beds and recent alluvial slopes as much as 15 meters (50 feet).

R.J. Russell (1928) mapped the Warner Mountains and also recognized recent displacement along the Surprise Valley fault. Russell reported that alluvial cones are displaced by the Surprise Valley fault. Russell mapped an approximately 16 km section of the Surprise Valley fault in detail (1 inch = 7400 feet) from Cottonwood Canyon north to Cedar Canyon. However, the base map is poor and the fault locations lack control. At a canyon about a mile north of Cottonwood Creek he reported a scarp in alluvium that was 10 to 20 feet (3 to 6.1 meters) high and had a scarp-slope angle of 33°. In addition to offset alluvial cones, Russell noted that traces of the Surprise Valley fault are associated with deeply incised drainages and hanging valleys, springs (both hot and cold), and truncated ridge spurs.

Gay and Anne (1958) generalized the Surprise Valley fault, showing it as a concealed fault along the west side of Surprise Valley (Figure 1). The fault is shown on the Alturas Sheet with dashed lines that would normally symbolize an approximately located fault. However, it was intended that the Surprise Valley fault be shown as concealed (C. Jennings, p.c., April 1990).

The California Department of Water Resources (CDWR, 1963) mapped the Surprise Valley ground water basin at a scale of 1 inch = 2 miles. The Surprise Valley fault is shown as a concealed fault and is based primarily on the interpretation of geophysical surveys (unspecified). Although it was stated that the Surprise Valley fault is a prominent structural feature delineated by a rugged fault scarp along the eastern front of the Warner Mountains, the geologic map (Plate 21) showed the Surprise Valley fault to be concealed by both Holocene and late Pleistocene deposits. Cross sections A-A' and B-B' (CDWR, p. 170 and 171) indicated that the Surprise Valley fault did not extend to the surface of Surprise Valley.

Slosson (1974) reported that the Surprise Valley fault is characterized by significant Holocene activity, based on the fresh scarps that delineate the fault zone and the numerous large landslides both in the Warner Mountains and the Hays Range. Slosson estimated that the long term slip rate for the Surprise Valley fault is 0.6mm/yr to 1mm/yr. Slosson did not map specific traces of the Surprise Valley fault.

Mapping by Hedel (1980, 1984) was done primarily to identify recently active traces of the Surprise Valley fault, based on the identification of geomorphic features indicative of recent faulting using aerial photographic interpretation and field mapping (shown in black on Figures 2a and 2b). Hedel stated that the accuracy of fault locations was generally ± 22.8 meters (75 feet).

Hedel interpreted several sets of aerial photographs, none of which are low sun angle. The principal set used was the 1974 U.S. Forest Service photos MO 01 (scale 1:15,840, color). Supplemental photos used by Hedel included U.S. Geological Survey black and white (scale 1:34,000) and small-scale black and white (scale 1:120,000) U.S. Forest Service photos. Field mapping was done in 1978 and 1979. Fault scarps were profiled and ages estimated using the methods described by Wallace (1977).

Hedel reported that the Surprise Valley fault is delineated by a nearly continuous, 84 km-long escarpment along the eastern front of the Warner Mountains. He also stated that many branching and secondary faults occur on the floor of Surprise Valley. Hedel reported that the geomorphic expression of the Surprise Valley fault includes many features indicative of Holocene normal faulting, such as scarps in alluvial and colluvial sediments deposited after the latest Pleistocene highstand of Lake Surprise (11 to 13 ka), incised drainages and small alluvial cones, and perched stream terraces (Figures 2a and 2b).

Strands of the Surprise Valley fault mapped by Hedel offset Holocene alluvial fans and lacustrine deposits (Figures 2a, 2b). Hedel based his estimates of the ages of surficial deposits on the assumption of the ages of Lake Lahontan lacustrine high stands. Thus, alluvial fans and other surficial deposits that occur below the 11 ka high stand are assumed to be Holocene in age.

Hedel mapped two tephra localities interbedded with late Pleistocene lacustrine deposits (Ql and Qd, Hedel, 1984), one north of Cedarville and one south of Eagleville (localities A and B, Figures 2a and 2b). These ash units were tentatively correlated with Trego Hot Springs tephra in Nevada described by J.O. Davis. The Trego Hot Springs tephra is stratigraphically above an ash unit (Wono tephra) that has a radiocarbon age of 24,480 $\pm$ 430 ybp. Davis estimated that the Trego Hot Springs unit is about 20 ka. Davis petrograpically correlated the tephra unit south of Eagleville with the Trego Hot Springs tephra in Nevada. The postulated source area for the Trego Hot Springs tephra is Mt. Mazama.

The northern section of the Surprise Valley fault from the vicinity of Fandango Pass (locality C) and to the north is concealed or obscured by massive landslides (Figure 2a). Hedel mapped discontinuous traces of the fault in and through the town of Ft. Bidwell. These faults are delineated by low scarps in Holocene alluvium and photo lineaments (Figure 2a). Hedel mapped traces of the Surprise Valley fault along the south flank of Mt. Bidwell (Figure 2a). These south-facing scarps form the headscarps of large landslides. However, a tectonic origin cannot be ruled out. There is a gap of about 2.6 km between the reported low scarps in Ft. Bidwell and the scarps along the south flank of Mt. Bidwell where Hedel did not map any faults (Figure 2a).

The central section of the Surprise Valley fault from the Fandango Pass area south to the Menlo Baths area (localities C and D, Figures 2a and 2b) is a nearly continuous fault as mapped by Hedel (1984). The fault offsets Holocene alluvium and is characterized by scarps in alluvial fans (e.g. scarp localities 8, 15, 16, 20, and 22, Figures 2a and 2b; Photo 2). There is an approximately 3.5 km long section of the Surprise Valley fault where Hedel mapped the fault east of the range front (just north of scarp locality 15, Figure 2b). R.J. Russell (1928) also reported that the Surprise Valley fault was located more toward the valley approximately at this location.

Hedel mapped the Surprise Valley fault south of the Menlo Baths area as concealed by late Holocene talus (Figure 2b). This part of the fault is delineated by a sharp, east-facing escarpment in bedrock. Hedel mapped thermal springs near the base of this escarpment, but does not show any specific geomorphic evidence of recent faulting (Figure 2b). Hedel (1980) stated that the escarpment is steep and has an abrupt base.

Hedel estimated that the maximum Holocene slip rate for the Surprise Valley fault is about 1 mm/yr. This slip rate was estimated based on the height of fault scarps in Holocene alluvial fans (based on the highest scarp profiled at scarp locality 16, Figure 2b). The long term slip-rate for the Surprise Valley fault is about 0.3mm/yr, based on the assumed maximum uplift along the fault in the last 15 my.

Aerial Photographic Interpretation and Field Observations

The Surprise Valley fault is generally well-defined and is delineated by geomorphic features indicative of Holocene normal faulting, such as abundant scarps in Holocene alluvial fans, incised or vertically offset drainages, and tonal lineaments (vegetation contrasts) in young alluvium (Figures 2a and 2b). Faceted spurs along most of the eastern side of the Warner Mountains are indicative of repeated normal displacement. Mapping by Hedel (1984) generally was verified, based on air photo interpretation and field inspection by this writer. The mapping of Hedel is generally very good, though somewhat generalized. Faults in red indicate where my mapping differs from the mapping of Hedel (Figures 2a and 2b).

The Surprise Valley fault north of the Fandango Pass area (locality C) is very complex and is generally concealed by massive landslides (Figure 2a). Hedel attempted to map strands through this complex, but it is almost impossible to verify his fault traces. He stated that the fault is obscure north of Fandango Pass. The discontinuous traces he does map have been modified by landsliding, erosion, or lacustrine processes (Figure 2a). Thus, these traces cannot be considered to be well-defined.

The northeast-trending bedrock escarpment just south of Mt. Bidwell is the most likely location for the northern continuation of the Surprise Valley fault (locality E, Figure 2a). However, the precise location of the fault is concealed by landslides. This southeast-facing escarpment forms both a fault scarp and a relatively linear headscarp of the landslide complex. The fault trace should be depicted as concealed or inferred through this area.

The Surprise Valley fault mapped by Hedel was mostly verified in the central parts of the fault zone from locality C to locality D (Figures 2a and 2b). Several large landslides occur near the southern end of this section of the Surprise Valley fault in the Eagle Peak quadrangle (Figure 2b). Hedel mapped a trace of the fault through a landslide mass about 2.4 km northwest of scarp locality 22 (Figure 2b). This trace was not verified by this writer through this landslide mass. The general location of the fault is probably near the base of the escarpment, but the location can only be inferred.

The Surprise Valley fault south of the Menlo Baths area (locality D) is delineated by a steep, undissected bedrock escarpment, but generally lacks specific geomorphic evidence of Holocene displacement, such as scarps in young alluvium, vertically offset drainages, or offset alluvial fans (Figure 2b). However, the lack of geomorphic features may be a function of the steepness of the scarp combined with the pluvial history of Surprise Valley. There are no young deposits at the base of the escarpment, except for very young talus deposits, and because the escarpment lacks dissection, there are no drainages to show any recent offset. The lack of dissection indicates that the scarp, which is composed of the same bedrock as the rest of the Warner Mountains, is probably very young. This assumption is substantiated by an offset alluvial fan at locality F (Figure 2b).

The major drainage at the Bare Creek Ranch is not offset by the southernmost extent of the Surprise Valley fault in the study area (locality N, Figure 2b). The drainage doesn't seem to have an increase of its gradient near the escarpment, doesn't exhibit the classic "wineglass" shaped cross section, and there are no scarps in the terraces. The lack of offset of this drainage indicates that recent activity along the Surprise Valley fault does not extend to the south.

The principal active trace of the Surprise Valley fault is delineated by well-defined scarps in alluvial fans, colluvium, and talus aprons (Figures 2a and 2b; Photos 2 and 3). Scarp profiles measured by Hedel (1980, 1984) and this author are indicative of Holocene displacement, based on work by Wallace (1978). In addition to these qualitative assessments, selected scarps profiled by Hedel were morphologically dated, based on a computer program by Nash (1987) (Table 1).

The value of the diffusivity constant c in this region is unknown. However, a relationship between the scarp height and c has been established by Pierce and Colman (1986) and Pearthree and others (1988). A linear regression that derives a diffusivity constant (C_L) to account for variation in height and climate in the western Basin and Range was developed by P.A. Pearthree:

$$C_L = [3.98 \text{ (scarp offset)} - 1.07] \times 10^{-4} \text{ m}^2/\text{yr}.$$

This equation allows an approximation of the diffusivity constant to be calculated for various scarps. The values of C_L derived for the morphologically dated scarps along the Surprise Valley fault are shown in Table 1.

To test the validity of the morphological dating, a large degraded scarp in Pleistocene alluvium was morphologically dated (scarp locality 19; SV 19 in Table 1). There were no obvious modifications to the scarp due to shoreline processes, although wave modification cannot be ruled out. The tc value for SV 19 was about 65 m^2, yielding a morphologic age of 26,018 years, assuming a C_L value of 25.2×10^{-4} m^2/yr.

Although the accuracy of the morphological ages of the scarps in the Surprise Valley study area is not known, it is interesting to note that the morphological ages seem to cluster around three events: one late Pleistocene event, one early Holocene event, and one mid- to late Holocene event. The two Holocene events inferred for the Surprise Valley fault are consistent with the assumptions of Hedel (1980), who postulated that at least two events occurred during the Holocene, one event 8-11 ka and one post 5 ka event.

Soil test pits were excavated at localities G and H (Figure 2b). Stream-cut exposures also allowed a reconnaissance assessment of the soil development on geomorphic surfaces in Surprise Valley. Soils developed on alluvial fans presumed to be Holocene in age are characterized by A-C horizons with little to no $CaC0_3$ development. The maximum pedogenic carbonate development was Stage I, which was observed at scarp locality 15 (Figure 2b). In contrast, soil profiles on late Pleistocene surfaces generally were much better developed. At a gravel pit north of Cedarville (locality I, Figure 2a) a Bt soil horizon was partly preserved (the upper part of the soil horizon had been removed due to gravel pit operations). The Bt horizon is characterized by moderate columnar structure, thin patchy clay films, and 7.5YR 3/2(M) color. The preserved Bt horizon is about 30 inches thick.

LAKE CITY FAULT

Literature Review

The Lake City fault is a northwest-trending, inferred fault located between Upper Lake and Middle Alkali Lake (Figures 1, 2a). The fault was first mapped by CDWR (1963) as concealed by alluvium, based on geophysical evidence (unspecified). In cross-section A-A' (CDWR, 1963, Figure 20. p.170), the Lake City fault is interpreted to be a vertical to near vertical fault with down to the east vertical displacement. The fault is inferred to come within about 300 meters of the valley floor.

Griscom and Conradi (1976) reported that the Lake City fault consists of a zone of faults up to 610 meters wide with at least two major strands. The fault zone was located based on gravity and magnetic surveys. It was not stated in any of the surveys what evidence led to the interpretation that the fault had down to the northeast displacement. They indicated that the interpreted fault is "shallow", although shallow was not quantified. Griscom and Conradi postulated that thermal springs along the fault zone resulted in some mineralization of buried alluvial deposits, as indicated by the small gravity highs and localized magnetic anomalies.

Hedel (1980, 1984) mapped surface traces of the Lake City fault zone, based on air photo interpretation and field mapping (Figure 2a). He reported that the fault zone is delineated by an obscure zone of low scarps and photo lineaments about 600 meters wide, bounded by more or less continuous faults on either side (Figure 2a). A large part of the southeastern Lake City fault is depicted as a dashed line and is delineated by an unspecified photo lineament. Hedel plotted the location of a buried fault, based on geophysical data from Hoover (unpublished), and Ford (CDWR, 1963) (Figure 2a). This concealed fault lies about 600 meters northeast of the southwestern fault mapped by Hedel (Figure 2a).

Hedel (1980) pointed out that the high shoreline of Upper Lake is about 6 meters lower than the high shorelines of both Middle Alkali Lake and Lower Lake, suggesting that there has been some amount of down-to-the-northeast vertical displacement along the Lake City fault. This is consistent with geophysical data that also indicates a down-to-the-northeast component of displacement. Hedel postulated that the northwest orientation of the Lake City fault should result in a component of strike-slip displacement. However, he stated that there is no geomorphic evidence supporting this assumption.

Aerial Photographic Interpretation and Field Observations

Traces of the Lake City fault mapped by Hedel generally are poorly defined and were not verified by this writer (Figure 2a). However, the subtle, moderately defined scarp at scarp locality 4 (Figure 2a) was verified, both on air photos and during the field inspection. The Lake City fault mapped by this writer is a series of moderately defined, discontinuous tonal lineaments that extend for about 6.5 km in Holocene alluvium. There is no sense of displacement evidenced by the geomorphic expression of the fault, with the exception of the moderately defined northeast-facing scarp in alluvium at Hedel's scarp locality 4 (Figure 2a). This scarp is very subtle (scarp-slope angle of 5°), and is associated with tonal lineaments (vegetation contrasts) that form a zone about 700 meters wide. Individual fault traces generally are no more than about 1200 meters long.

Geomorphic evidence for the Lake City fault as a surface feature is weak. However, the northeast-facing scarp and the lower level of Upper Lake, as well as the discontinuous tonal lineaments in young alluvium do suggest the presence of a fault. The estimated down to the northeast offset of the Lake City fault is also supported, although weakly.

"VALLEY FLOOR" FAULTS

Literature Review

Hedel (1980, 1984) mapped many short, discontinuous, generally north-trending faults east of the Surprise Valley fault (Figures 2a and 2b). These faults are generally delineated by very low, east-facing scarps and photo lineaments in latest Pleistocene and Holocene lacustrine deposits. None of the faults mapped by Hedel face west (antithetic). This zone of faults is up to 2.6 km wide east of Cedarville (Figure 2a).

Hedel was influenced by the structural interpretation of geophysical surveys by CDWR of the down-thrown block along the Surprise Valley fault. Cross-section A-A' (CDWR, 1963, Figure 20, p. 170) showed a steeply to vertically dipping fault located east of the main trace of the Surprise Valley fault. Displacement is down to the east, similar to the Surprise Valley fault. Bedrock is offset and the fault extends into and offsets the overlying alluvium, but apparently only comes to within about 600 meters of the valley floor. However, CDWR also indicated that the Surprise Valley fault does not reach the surface.

Hedel stated that the zone of "valley floor" faults delineated by low scarps and photo lineaments is a surface expression of the Surprise Valley crustal block buried beneath basin-fill deposits. Vertical offset of the crustal block has propagated to the surface. The scarps that delineate these faults generally are very low and have shallow scarp-slope angles. Hedel explains the shallow scarp-slope angle as due to the fine-grained nature of the offset deposits.

The majority of the "valley floor" faults are located east of the vicinity of Cedarville - most are located along the western shore of Middle Alkali Lake (Figure 2a). The highest scarp of the valley floor faults is 1.8 meters (scarp locality 21, Figure 2).

Aerial Photographic Interpretation and Field Observations

Most of the short, discontinuous faults mapped by Hedel east of the principal trace of the Surprise Valley fault are poorly defined and were not verified by this writer, based on air photo interpretation and field inspection (Figures 2a and 2b). However, the USDA air photo coverage has relatively poor lighting conditions (near noon) and the scale is not ideal (~1:26,000), so there may be some low scarps that I was unable to detect. Although this may be true, prior experience evaluating faults in marshy areas indicates that minor normal fault rupture juxtaposes different materials, or materials that have different degrees of saturation, which would produce a distinct tonal contrast. Tonal contrasts where Hedel's traces are located generally were not observed. I briefly interpreted air photos used by Hedel (MO 01, color, scale about 1:15,000) at the US Forest Service office in Alturas in Sept 1989, but still was unable to verify most traces.

Some of the scarps that I could verify may be recessional shorelines rather than faults and are indicated as such on Figures 2a and 2b. The scarps mapped by Hedel all face east, and most parallel contours, which also suggest shorelines. Traces that cross contours generally were not verified. Scarp profile data supplied by Hedel indicates that these features generally are low (scarp heights range from 0.5 meters to almost 2 meters) and the scarp-slope angles are extremely flat (4 degrees to 14 degrees maximum). These scarps are all in very young alluvium and it is difficult to reconcile their flat slope angles with the inferred young age. However, these profiles are more consistent with shoreline features such as beach ridges and wave-cut benches. There are a few features mapped by Hedel that were verified as faults by this writer, based on air photo interpretation and field observations. These features are indicated by a red check mark on Figures 2a and 2b (localities J - M). Other scarps not related to shoreline features conceivably could be related to liquefaction. The problem with invoking liquefaction as the cause of these scarps is that there seems to be a lack of such scarps on the eastern side of Surprise Valley, although I have not rigorously checked this.

WEST SIDE OF HAYS RANGE

The west side of the Hays Range forms the eastern side of the Surprise Valley graben. North-trending faults along the western side of the mountain range were shown by I.C.

Russell (1885, Plate XLIV) in a small-scale map of post-Quaternary faults in the northwestern Basin and Range (Figure 3). These faults were not verified as sufficiently active or well defined by this writer, except for a 5 km long segment just north of Lower Lake (locality O, Figure 2b), based on reconnaissance air photo interpretation. Moderately to well-defined scarps, troughs, and tonal lineaments in Pleistocene older alluvium (?), Holocene alluvium. and eolain deposits delineate this unnamed fault (locality O, Figure 2b).

SEISMICITY

Seismicity in the Surprise Valley study area is plotted on Figures 2a and 2b, based on reported earthquakes and instrumentally recorded events (Hedel, 1980, 1984). The quality of instrumentally recorded events is unknown. Data from CIT (1985) shows no A and B quality events in the Surprise Valley study area. Hedel indicates that several events occurred in the vicinity of Cedarville that had Modified Mercalli intensities of about III (Figure 2a).

CONCLUSIONS

SURPRISE VALLEY FAULT

The Surprise Valley fault is an 84 km long, generally north-trending normal fault with about 3800 meters of cumulative vertical displacement (down to the east) (Hedel, 1980). Hedel (1984) reported that the Surprise Valley fault has a Holocene slip rate of about 1 mm/yr.

The Surprise Valley fault north of the Fandango Pass area (locality C) is poorly defined and is concealed or obscured by massive landslide deposits (Figure 2a). Short, discontinuous traces mapped by Hedel (1984) were not verified by this writer.

The central section of the Surprise Valley fault from the vicinity of Fandango Pass south to the Menlo Baths area (localities C and D, Figures 2a and 2b) is generally well-defined and is delineated by geomorphic features indicative of Holocene normal faulting, principally well-defined east-facing scarps in Holocene alluvial fans. Mapping by Hedel (1984) was mostly verified by this writer, based on air photo interpretation and field observations. There were only minor disagreements with respect to the location of fault traces, which are indicated in red on Figures 2a and 2b.

Scarps in alluvial fans are characterized by profiles indicative of Holocene displacement, based on the data of Wallace (1977). Morphologic dating of selected scarps measured by Hedel (1984) using a computer program by Nash (1987) also indicate Holocene activity (Table 1).

The Holocene age of the offset alluvial fans was inferred by Hedel based on the position of the alluvial fans relative to the high shorelines of latest Pleistocene Lake Surprise and the observation that the alluvial fans had not been modified by shoreline processes. Poorly developed soil profiles observed by this writer on selected alluvial fans further supports a

Holocene age (localities G and H, scarp locality 15, Figure 2b).

The southern section of the Surprise Valley fault south of the Menlo Baths area (locality D) is delineated by an undissected, east-facing bedrock escarpment (Figure 2b). Hedel (1984) mapped this section of the fault as concealed by Holocene talus deposits. Specific geomorphic evidence of Holocene normal faulting is mostly lacking, although an offset alluvial fan at locality F and the steep, undissected bedrock escarpment are suggestive of Holocene activity (Figure 2b).

LAKE CITY FAULT

The Lake City fault was originally mapped by CDWR (1963) as a concealed, northwest-trending fault characterized by an unknown amount of down-to-the-northeast displacement. The presence of this fault was based on geophysical data (unspecified). Griscom and Conradi (1976) reported that the Lake City fault is a northwest-trending zone of faults up to 610 meters wide, based on gravity and magnetic surveys. Small gravity highs were inferred to indicate localized zones of hydrothermal mineralization in alluvium along the fault.

Hedel (1984) mapped a broad, discontinuous zone of vague scarps and tonal lineaments along the inferred trace of the Lake City fault (Figure 2a). Traces of the Lake City fault generally are moderately defined at best and mapping by Hedel was mostly not verified (Figure 2a). The evidence for the Lake City fault as a surface feature is weak. However, the northeast-facing scarp at scarp locality 4 and the lower level of Upper Lake, as well as the discontinuous tonal lineaments in young alluvium do suggest the presence of a fault (Figure 2a). The inferred down to the northeast offset along the Lake City fault is also weakly supported.

"VALLEY FLOOR" FAULTS

Hedel (1984) mapped many short, discontinuous, generally north-trending faults east of the Surprise Valley fault that locally form a zone up to 2.6 km wide (Figures 2a and 2b). These faults are generally delineated by very low, east-facing scarps and photo lineaments in latest Pleistocene and Holocene lacustrine deposits. Most of the faults mapped by Hedel were not verified or are poorly defined (Figures 2a and 2b). Many of the north-trending features east of the Cedarville area conceivable are shoreline features, based on trends that parallel the shoreline of Middle Alkali Lake (Figure 2a). However, some of the features mapped by Hedel were verified and probably are secondary faults that offset Holocene alluvium (e.g. localities J - M, Figures 2a and 2b).

WEST SIDE OF HAYS RANGE

The 5 km long, unnamed fault on the west side of the Hays Range is moderately to locally well defined and offsets Holocene alluvium (locality O, Figure 2b). It is possible that these geomorphic features were formed by lateral spreading due to earthquake shaking, but the general continuity over a distance of about 5 km is more convincingly explained by faulting.

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active " and "well-defined" (Hart, 1988).

SURPRISE VALLEY FAULT

Zone for special studies well-defined traces of the Surprise Valley fault mapped by Hedel (1984) and Bryant (this report) as depicted in Figures 2a and 2b (highlighted in yellow). Principal references cited should be Hedel (1980, 1984) and Bryant (this report).

LAKE CITY FAULT

Do not zone for special studies traces of the Lake City fault. This zone of tonal lineaments is moderately to poorly defined and lacks associated geomorphic evidence of systematic strike-slip or vertical displacement.

"VALLEY FLOOR" FAULTS

Zone for special studies selected faults east of the Surprise Valley fault mapped by Hedel (1984) and Bryant (this report) as depicted in Figures 2a and 2b (highlighted in yellow). Principal references cited should be Hedel (1984) and Bryant (this report).

WEST SIDE OF HAYS RANGE

Zone for special studies the unnamed fault at locality O mapped by Bryant (this report) as depicted in Figure 2b (highlighted in yellow). Principal reference cited should be Bryant (this report).

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TABLE 1 - SCARP PROFILES, SURPRISE VALLEY FAULT[1]

Label[2]	Scarp Offset	tc (m^2)	r^2	C_L[3] ($x10^{-4} m^2/yr$)	Age[4]
SV 07	1.53	5.78	0.9075	5.02	12,000
SV 09	2.22	2.04	0.9870	7.77	3,000
SV 10[5]	1.30	3.69	0.9662	4.10	9,000
SV 15	2.69	2.59	0.9733	9.64	3,000
SV 18	5.49	7.34	0.9926	20.78	4,000
SV 19	6.60	65.57	0.9764	25.20	26,000
SV 21[5]	1.30	4.10	0.9640	2.91	3,000

1. After Nash (1986,1987)
2. Number of scarp corresponds to Hedel (1984) scarp locality.
3. C_L = [3.98 (scarp offset) - 1.07] x $10^{-4} m^2/yr$. *From P.A. Pearthree, University of Arizona.*
4. Morphologic age rounded to nearest 1 x 10^3 yrs.
5. Scarp probably modified.

Photo 1 (to FER-217). View south of the Warner Mountains, a west-tilted fault block. The Surprise Valley fault is located at the base of these tilted Miocene volcanic rocks.

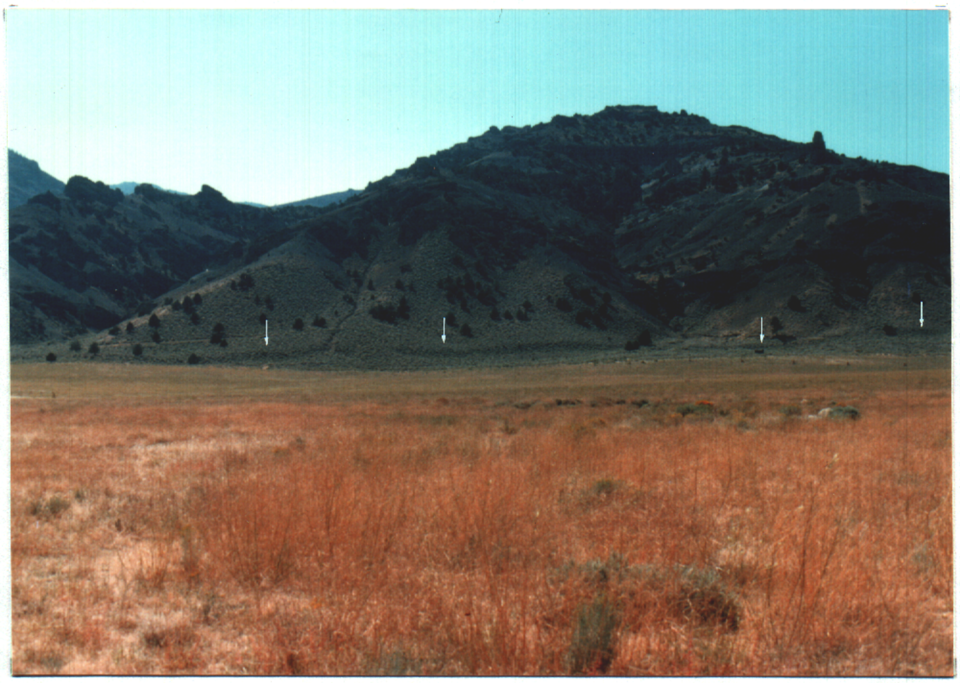

Photo 2 (to FER-217). Faceted spurs, vertically offset or incised drainages, and sharp scarps in Holocene alluvial fans (arrows) delineate the active trace of the Surprise Valley fault, view west. This section of the Surprise Valley fault is at Hedel's scarp locality 15 (refer to Figure 2b).

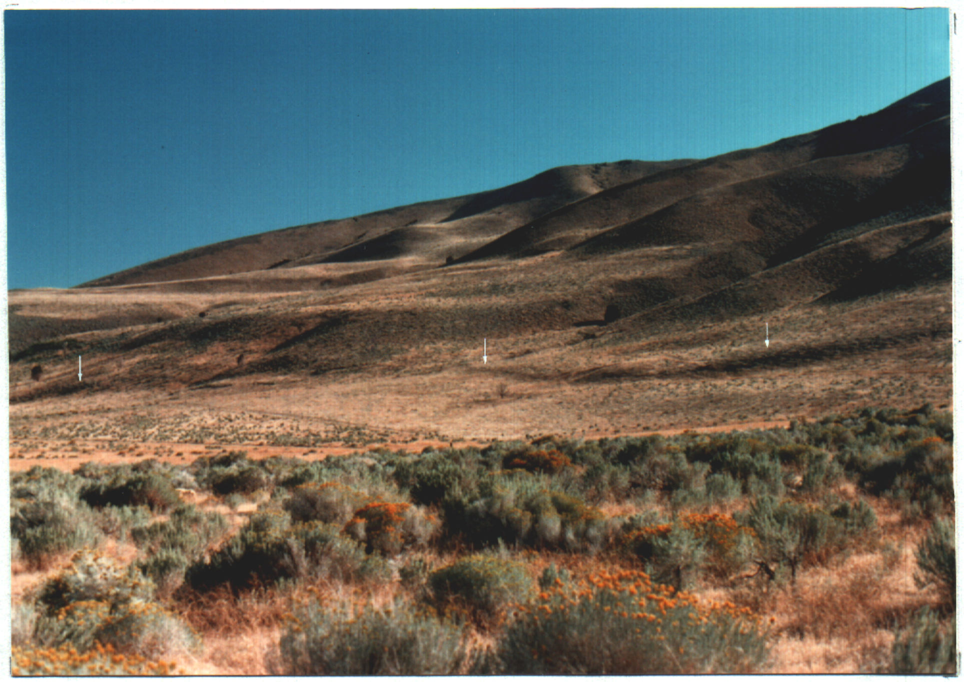

Photo 3 (to FER-217). Shorelines of Pleistocene Lake Surprise form prominent benches along parts of the southern Surprise Valley fault, view southwest. The Surprise Valley fault (arrows) offsets a Holocene alluvial fan at locality G (refer to Figure 2b).